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14. ABSTRACT
The ultimate goal is the routine use of high-fidelity, turbulent flow modeling for the design of future waterjets. The purpose of the proposed effort is to carefully quantify the ability of a state-of-the-art homogeneous multiphase RANS solver, UNCLE-M, to predict the performance of marine propulsors over a range of cavitation numbers from single phase flow through thrust breakdown and over a variety of operating conditions. The effort is a code verification and validation effort focused on waterjet applications. During this FY computations have been completed and comparisons have been used to qualify the effectiveness of the tools to predict cavity size and shape. In addition, the tools have been used to predict cavitation breakdown performance of an as yet untested waterjet.

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Prediction of Waterjet Cavitation: End of Year FY08
11 August 2008

Submitted by

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UNCLE-M is a flow solver used for the simulation of steady and unsteady high-Reynolds number, turbulent, all Mach-number, multiphase flows. The governing equations are the multiphase Reynolds-averaged Navier-Stokes (RANS) in homogeneous mixture form [1]. UNCLE-M has been applied to a variety of compressible and incompressible multiphase flows, from hydrofoils and control surfaces to high-speed supercavitating vehicles (with and without 6DOF coupling) and marine propellers. As a preliminary to waterjet flow analysis, cavitation thrust breakdown in several well-studied unducted propellers was modeled using UNCLE-M. This entailed modeling operation over a range of conditions from single-phase design flow to massively separated cavitating flow. Both of these efforts relied successfully on overset gridding technology. Direct comparison with cavity shapes, thrust and torque yielded superlative results. The overset gridding facilitated a significant refinement of the mesh used to support the cavity flow. This concurs with the suggestion made in Lindau(2005): *In the simulation of a propulsor operating with large-scale cavitation, mesh resolution is critical for the accurate prediction of cavity shape.* It was also shown in that work that surface integral properties like thrust and torque were somewhat less mesh dependent. Formal verification and validation of the preliminary efforts are underway and will be reported in publications and submissions to the ONR

Surface-craft waterjet propulsion is characterized by operation at low cavitation indices. Therefore, unlike the typical marine propulsor operated by the Navy, there is almost always some cavitation present during the routine operation of a waterjet. Furthermore, cavitation breakdown, i.e., cavitation sufficient to cause significant loss of thrust and torque, can occur at conditions very close to the design point. For the analysis and, more importantly, the design of advanced waterjets, a computational tool capable of reliably and accurately predicting the operation of a waterjet, including single-phase as well as cavitation breakdown performance, is required.

With regard to waterjet design there is a critical need for accurate tools in both the preliminary and detailed design phases. A validated tool that can accurately predict the performance of a given configuration is obviously necessary for the detailed design phase. However, today there is a complete absence of *preliminary* design guidance related to expected breakdown performance. The most cost-effective way to develop these low-fidelity preliminary design tools for breakdown performance is to carry out systematic parametric studies using an accurate high-fidelity flow solver and use the results of these studies to build preliminary design guidance rules.

In addition to the open propeller cavitation breakdown modeling, the as-proposed, preliminary phase of this effort was intended to result in the cavitation breakdown analysis of a novel waterjet design, the ONR sponsored Axial Flow Water Jet (ONR-AxWJ). However, in response to program needs, the scope of preliminary work was altered, and only single-phase modeling was accomplished. Rather than pursuing a cavitation breakdown investigation, these investigators were tasked with definition of new optimal design conditions for the candidate waterjet. The standard RANS-based design tools (OVER-REL) employed at ARL/PSU were used to accomplish this task. The new, more appropriate operating conditions and performance around the new operating conditions were so-determined. The so-determined conditions thus define the starting point for an in-cavitation and thrust breakdown investigation. Results associated with definition of the new single-phase design condition are in preparation for publication and have been communicated to the ONR et al. via program review and subsequent private communications.

RESULTS:

The computed and observed (Boswell 1971) cavity shape for the open propeller designated P4381 are shown in Fig. 1. The computed result shows the cavity outlined by the liquid volume fraction contour at α_v=0.5. The computed result also shows the propeller surface colored by pressure.

The computed and observed cavity shape in another open propeller, the INSEAN E779A (Salvatore 2002) are shown in Fig. 2.

Finally the preliminary results obtained on the original point-matched grid used to determine the single phase operating point are shown in Fig. 3. Here in part (a) of the figure, the rotating and the stator hub surfaces are shown colored by pressure at two cavitation indices, one prior to severe breakdown (σ=0.2187) and the other deep in breakdown (σ=0.1539). These solutions were obtained utilizing a slug inflow velocity profile and the pressure outflow profile determined with single phase design computations during the initial phase of this investigation. It is reiterated (from previous reporting) that the lack of more appropriate inflow and outflow conditions suggests that further investigation and coordination with experimental results is needed.

CONCLUSIONS and RECOMMENDATIONS:

Computations of propeller and water jet cavitation have been obtained and presented. The open propeller solutions have been presented in particular for quality of cavity shape. It has previously been demonstrated that the current modeling method is well suited to predicting the thrust and torque of open propellers into cavitation breakdown at a range of loading conditions (Lindau et al. 2005). It is concluded that when applied with sufficient grid resolution, there are similarly no evident limitations in the present method in applicability to predicting large-scale, open propeller vaporous cavity shapes and sizes. Finally, plausible but unsubstantiated preliminary results have been presented for the test axial flow water jet, Ax-WJ1. It is suggested that further work be devoted to obtaining better inlet and exit profiles for the water jet both in single phase and in cavitation operation. It is expected that this data may be obtained by both numerical and physical experiments and investigations. More numerical solutions are required to verify a sufficiently small level of grid dependency, and reasonable convergence in the computed solutions. Finally a comparison between the numerically predicted and physically obtained results must be made. Then reasonable qualifications may be detailed for future application of the solution methodology to water jet cavitation performance.

Boswell, R.J., "Design, Cavitation Performance and Open-Water Performance of a Series of Research Skewed Propellers," Naval Ship Research and Development Center, Washington, D.C., Report No. 3339, 1971.

Kunz, R. F., Boger, D. A., Stinebring, D. R., Chyczewski, T. S., Lindau, J. W., Gibeling, H. J., Venkateswaran, S., and Govindan, T. R., *A Preconditioned Navier-Stokes Method for Two-Phase Flows with Application to Cavitation Prediction*, Comput. Fluids, **29**, pp. 849–875, 2000.

Lindau, Jules W., David A. Boger, Richard B. Medvitz and Robert F. Kunz, *Propeller Cavitation Breakdown*, Journal of Fluids Engineering 995-1002, September (2005).

Salvatore, F., F. Pereira and F. Di Felice, *Numerical Investigation of the Cavitation Pattern on a Marine Propeller: Validation vs. Experiments,* INSEAN, Rome, Italy 2002.

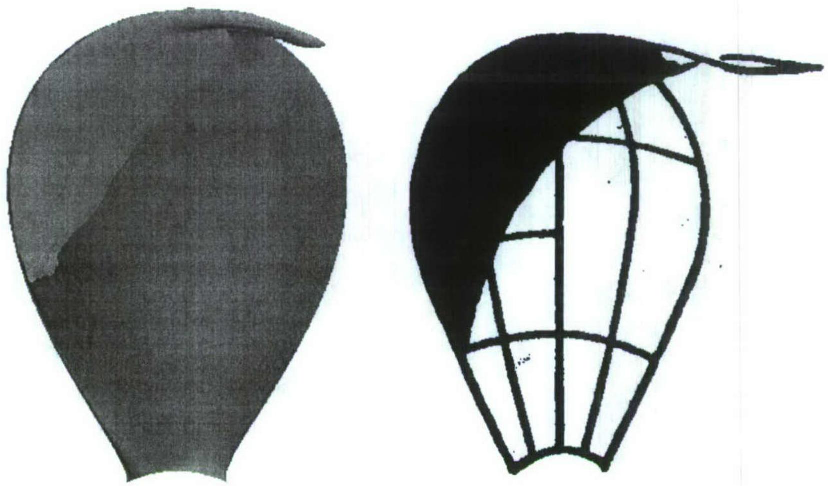

Figure 1: Propeller P4381, comparison of computed cavity shape with sketch from Boswell (1971)

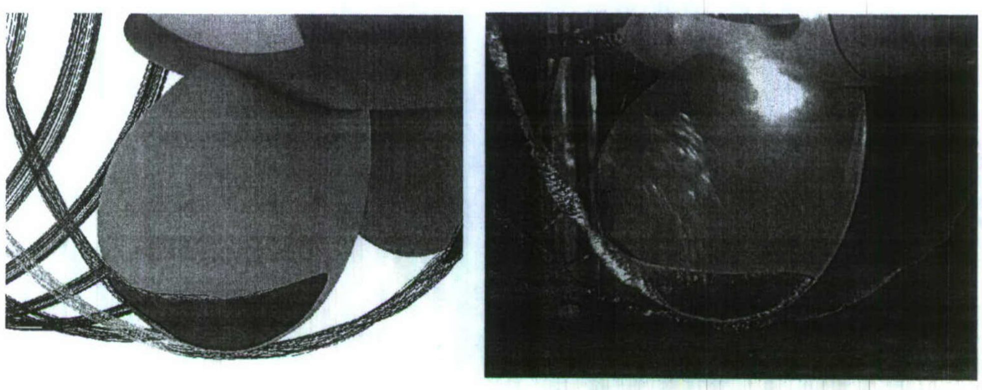

Figure 2: Computed and photographed (Salvatore 2002) cavitation on the INSEAN E779A propeller at J=0.71 and σ_n=1.76. Computed solution shows pink isosurface of vapor volume fraction (α_v=0.9) and selected streamlines colored by vapor volume fraction, tracking cavitation in the tip vortex structure.

a)

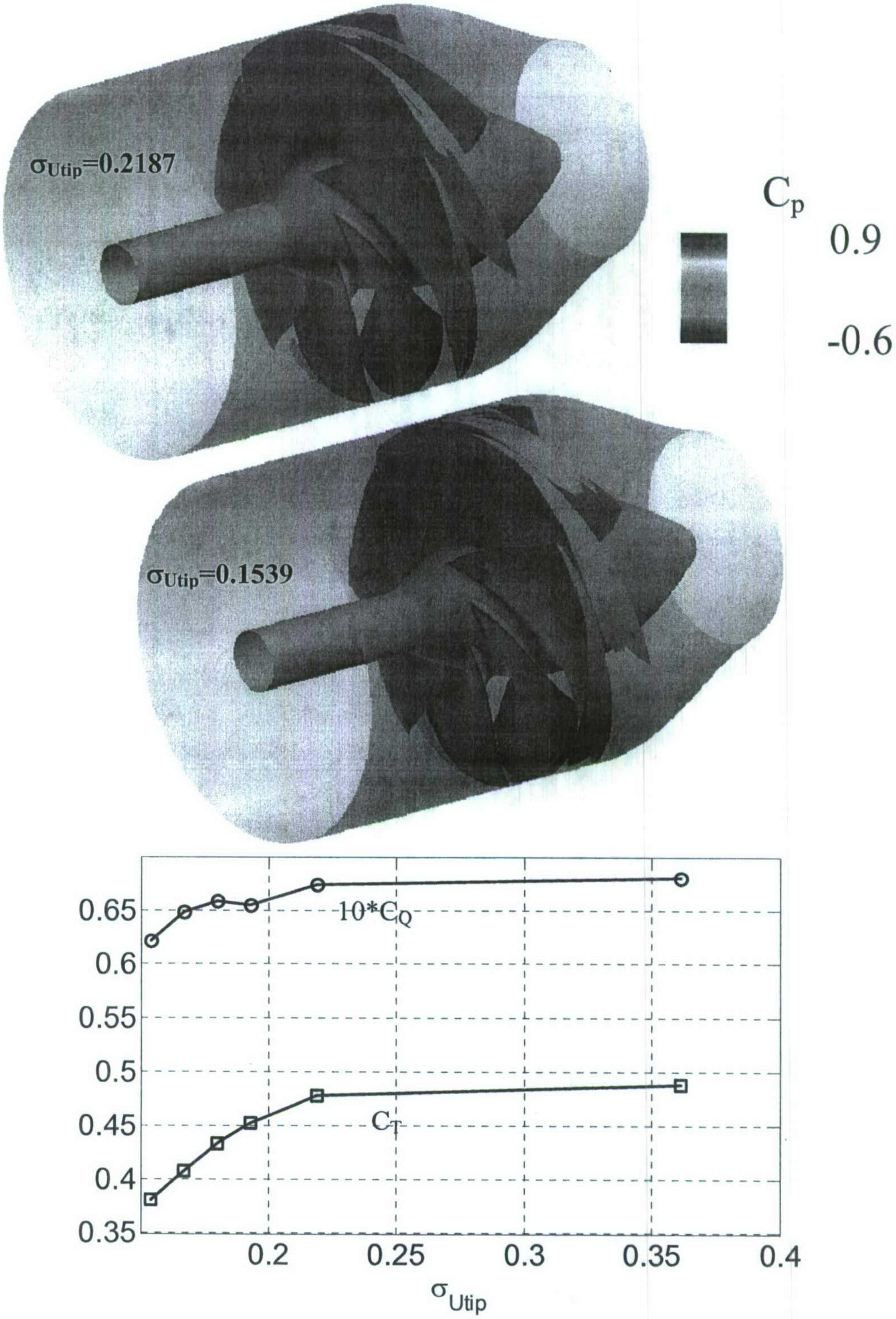

Figure 3: Preliminary computations for the AxWJ-1, J=0.492.

a) Isosurfaces of vapor volume fraction (α_v=0.5) rotor and hub of stator region colored by pressure. Cavitation index indicated on plotted results.

b) Breakdown profile, torque and axial force coefficient (forces on rotating surfaces only) at constant speed and mass flow.